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MEMORANDUM REPORT ARBRL-MR-03262

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BOUNDARY-LAYER TRIP EFFECTIVENESS AND  
COMPUTATIONS OF AERODYNAMIC HEATING  
FOR XM797 NOSE-TIP CONFIGURATIONS

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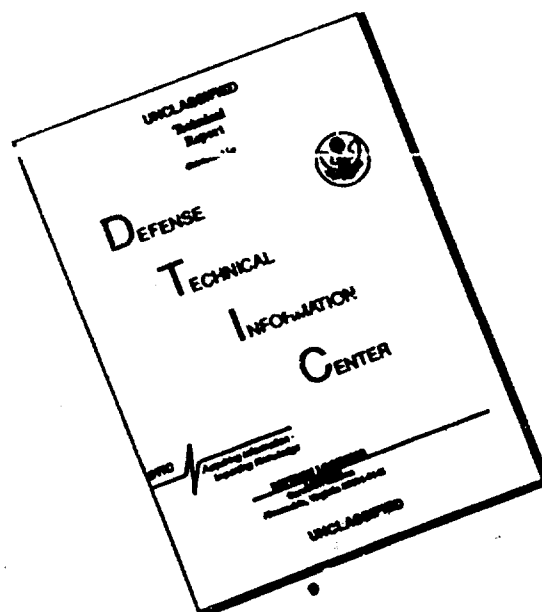
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Army is examining a new concept for limiting the range of the training round for the M735 projectile. This training round, designated the XM797, now employs an explosive placed within the nose cap which is ignited by aerodynamic heating. This report documents results of a recent firing program conducted at the BRL Transonic Range in which M735 projectiles with modified nose-tips were tested. The purpose of these tests was to determine the effectiveness of boundary-layer trips in generating turbulent boundary layers on		

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20. ABSTRACT (Continued)

the projectile nose. Also reported are results of computations of the in-depth temperature response of XM797 nose-cap configurations for several flight conditions.

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## I. INTRODUCTION

The Army is currently performing development testing of projectiles to determine the feasibility of a new concept for a training round for the M735 projectile. This training round, designated the XM797, now employs an explosive placed within the nose cap which is ignited by aerodynamic heating.

The purposes of this report are to: (1) document the results of a recent firing program conducted at the BRL Transonic Range in which M735 projectiles with modified nose tips were tested and (2) report the results of computations of the in-depth temperature response of XM797 nose-cap configurations for several flight conditions.

## II. TRANSONIC RANGE TESTS

### A. Background

The primary purpose for the firing tests was to determine the effectiveness of two boundary-layer trip configurations, one recommended by BRL (Trip-A) and the other simulating the configuration employed by AVCO on the latest version of the XM797 (Trip-B).

### B. Models

The projectiles tested were standard M735 shell which were modified by cutting off the nose caps and replacing them with steel parts machined to have the outer configuration of the XM797. Three nose-cap configurations were tested: no trip, Trip-A, and Trip-B. A picture of the two shapes with boundary-layer trips is shown in Figure 1. Both boundary-layer trips were formed using a coarse knurl having approximately 1.5mm between parallel ridges of the knurl. Both boundary-layer trips were 6mm in length. TRIP-B started at approximately 1.5mm from the nose and the TRIP-A started 19mm from the nose.

### C. Test Procedure

A summary of the test conditions is given in Table 1. Tests were conducted for three conditioning temperatures to simulate arctic, standard, and desert climates. Spark shadowgraphs of the flow over the shell and standard aerodynamic coefficient data were obtained. The aerodynamic coefficient data are also summarized in Table 1.

### D. Discussion of Spark Shadowgraphs

Spark shadowgraphs of the nose region of the shell for each test are shown in Figures 2, 3, and 4 for no trip, TRIP-A, and TRIP-B, respectively. The range data show that angles of attack ( $\alpha$ ) and angles of sideslip ( $\beta$ ) varied from 0.1 to 2.2 degrees at the spark-shadowgraph station. The film plates are located in the horizontal plane and therefore show angles of sideslip but do not show angles of attack.

Figures 2a and 2c indicate that the boundary layer remains laminar on the 12-degree conical section and becomes transitional on the 8-degree conical

section. The boundary layer is not definitely fully turbulent until the cylindrical body is reached. Figures 2b and 2d indicate that the boundary layer becomes transitional near the junction of the 12- and 8-degree conical sections and that the flow is turbulent midway along the 8-degree conical section. No consistent trend with wall temperature is observed.

Figures 3a, 3b, and 3c show that Trip-A has had a significant effect on the boundary-layer development. The boundary layer appears to be successfully tripped in that there is no tendency for the boundary-layer to relaminarize downstream of the trip. Also, note that the outer edge of the boundary layer is irregular downstream of the trip in contrast to the outer edge of the viscous layer for Figure 2. It is also apparent that the lee side viscous layer is more effectively tripped than the wind side (bottom side in these pictures); Figure 3c shows this effect to be substantial for a projectile yaw of  $2.2^\circ$ . This suggests that the BRL trip configuration is not fully satisfactory.

Figures 4a, 4b, and 4c show that Trip-B is not as effective as Trip-A. Trip-B generates some turbulence on the nose; but, on the aft part of the 8-degree conical section, the turbulence seems to be decaying and the boundary layer becoming thinner, which indicates a tendency toward relaminarization of the boundary layer. Looking closely in the vicinity of the trip, it is apparent that the trip disturbs the boundary layer; however, the boundary layer shows a tendency toward relaminarization immediately downstream of the trip. Past experience in the BRL wind tunnels has shown that boundary-layer trips placed too far forward on a model were not effective in generating a turbulent boundary layer even though the trip provided considerable disturbance to the boundary layer.

### III. AERODYNAMIC HEATING COMPUTATIONAL STUDY

#### A. Background

A series of computations of the in-depth temperature response of XM797 nose-cap configurations to aerodynamic heating has been accomplished using the Acurex/Aerotherm ABRES Shape Change Code - 1979 Version (ASCC-79), Reference 1. The purpose of this brief computational study was to examine the effect on the in-depth temperature resource of varying the location of the powder cavity in the nose for the XM797. Recent firing tests, Reference 2, indicated that

- 
1. Sandhu, S. S., and Murray, A. L., "Reentry Vehicle Technology (REV-TECH) Program. Volume III. Improved Capabilities of the ARBES Shape Change Code (ASCC 79)," Acurex Report TR-79-10/AS, Acurex Corporation/Aerotherm, 485 Clyde Avenue, Mountain View, California 94042, prepared for Space and Missile Systems Organization, Air Force Systems Command, Los Angeles, California 90009, July 1979.
  2. Hudgins, H., Private Communication, Results of XM797 August 1981 Firing Data.

the XM797 functioned; however, the functioning time was, in general, too soon for hot conditioned rounds and too late for cold conditioned rounds. Additionally, the difference between the functioning times for the hot and cold conditioning extremes was greater than desired.

#### B. Model and Flow Field Conditions

A schematic drawing of the model geometry used in this study is shown in Figure 5. The internal powder cavity was modelled as an adiabatic cavity. Results have been obtained for three cavity geometries indicated as A(original configuration), B, and C.

In performing a computation using the ASCC-79 code, a considerable quantity of input data is required. The values used for the surface roughness parameters are given in Table 2. Of particular interest here, the location of boundary-layer transition was fixed at 15mm from the tip of the model.

#### C. Discussion of Computed Results

Examples of the in-depth temperature response as a function of time are shown in Figures 6 and 7. These figures display the temperature-time history of points P2, P3, and P4 (Figure 5) for cavities A, B, and C, respectively. Firing test functioning times for the original cavity configuration (A), correlated well with the time for the temperature at position P2 to reach 1000R. This makes it convenient (and sufficiently accurate for comparative purposes here) to evaluate the effect of the different cavity configurations by comparing the time for positions P2, P3, and P4 to reach 1000R.

Using these criteria, Figure 6a indicates a functioning time of 2.55 seconds and 3.5 seconds for cavities A and C, respectively, for cold conditioned shell. Figure 6b indicates a functioning time of 1.65 seconds and 2.35 seconds for cavities A and C, respectively, for hot conditioned shell. These results predict that changing the cavity location will have a significant effect on the functioning time. Further, these results indicate that the difference between the functioning time for the different conditioning temperatures ( $dt = 2.55 - 1.65 = 0.90$  for A and  $dt = 3.50 - 2.35 = 1.15$  for B) is increased by moving the cavity rearward in the nose cap.

Figure 7 indicates a functioning time of 2.1 seconds for hot conditioned shell and 3.2 seconds for the cold conditioned shell for cavity B. The functioning time difference is  $3.2 - 2.1 = 1.10$  seconds.

### IV. CONCLUSIONS

1. Examination of the spark shadowgraphs of the flow over the simulated XM797 nose caps indicate that:

a. The BRL design boundary-layer trip (Trip-A) resulted in a turbulent boundary-layer immediately downstream of the trip.

b. The boundary-layer trip designated as Trip-B did not produce a reliable turbulent boundary-layer immediately downstream of the trip; however,

Trip-B did produce greater turbulence in the boundary layer development than the no-trip cases.

c. Small projectile yaw causes considerable asymmetry in the boundary layer development. This makes it important that any boundary-layer trip be placed where it will perform effectively.

2. The computational results indicate that:

a. Moving the powder cavity rearwards results in a delay in the functioning time.

b. Moving the powder cavity rearward does not result in a significant reduction of the difference in functioning times between hot and cold conditioned shell.

#### V. RECOMMENDATION

It is recommended that the configuration of the boundary-layer trip employed on the XM797 be placed no closer to the projectile tip than 15mm and that the trip extend to 26mm from the projectile leading edge.



TRIP-A



TRIP-B

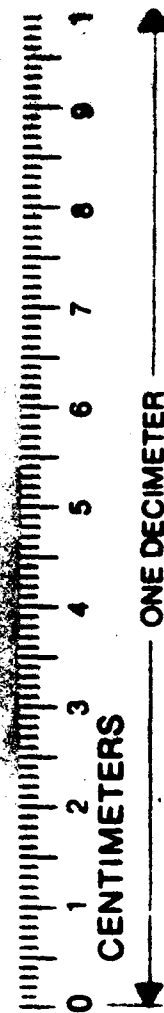


Figure 1. Nose-Tip Photograph with BL Trip-A and BL Trip-B

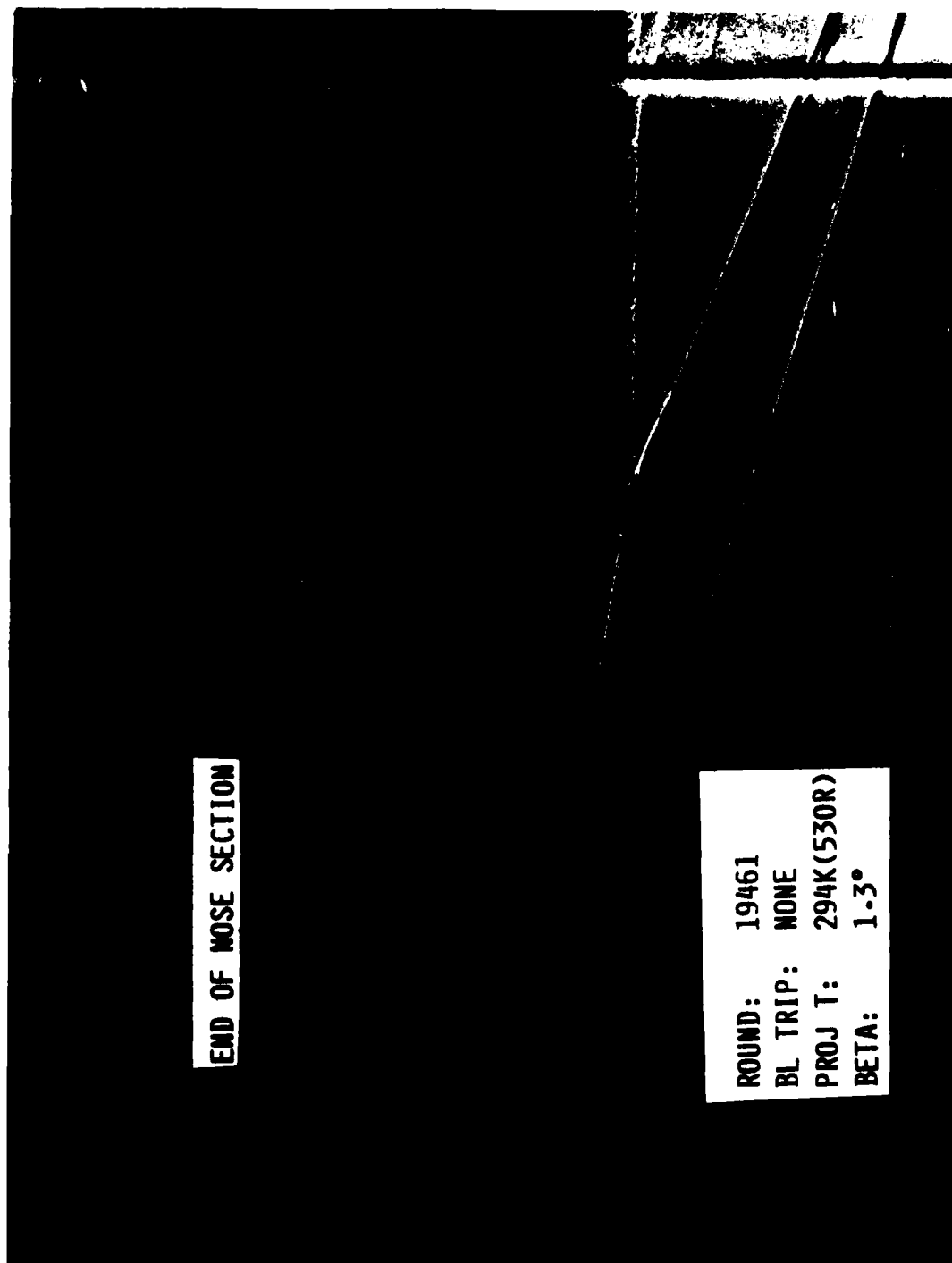


Figure 2. Spark Shadowgraphs, No BL Trip

a. Round 19461, Wall Temp = 294K(530R),  $\beta = 1.3^\circ$

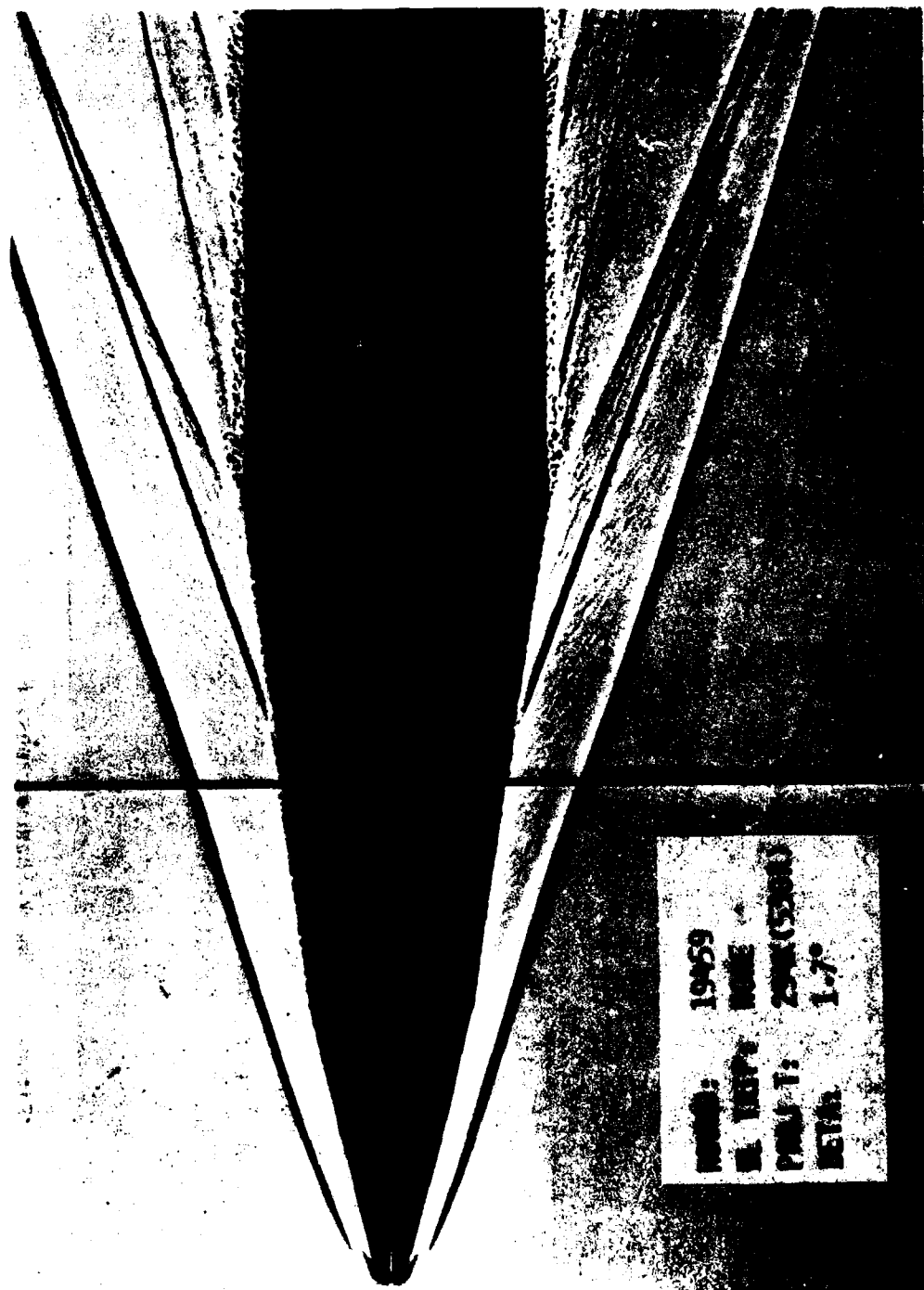


Figure 2. Spark Shadowgraphs, No BL Trip  
 b. Round 19459, Wall Temp = 294K(530R),  $\beta = 1.7^\circ$

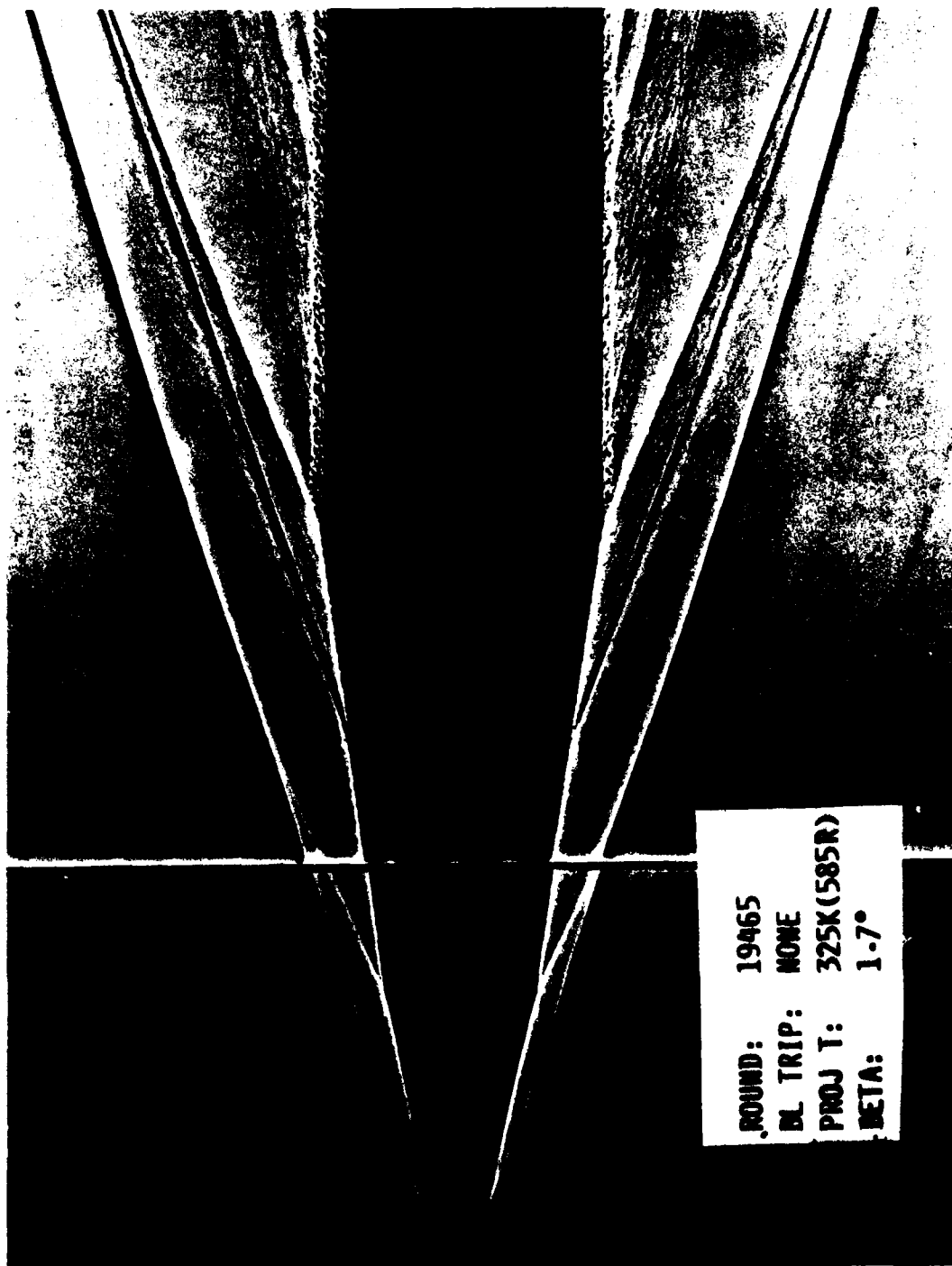


Figure 2. Spark Shadowgraphs, No BL Trip  
c. Round 19465, Wall Temp = 325K(585R),  $\beta = 1.7^\circ$



Figure 2. Spark Shadowgraphs, No BL Trip

d. Round 19463, Wall Temp = 325K(585R),  $\beta = 1.9^\circ$

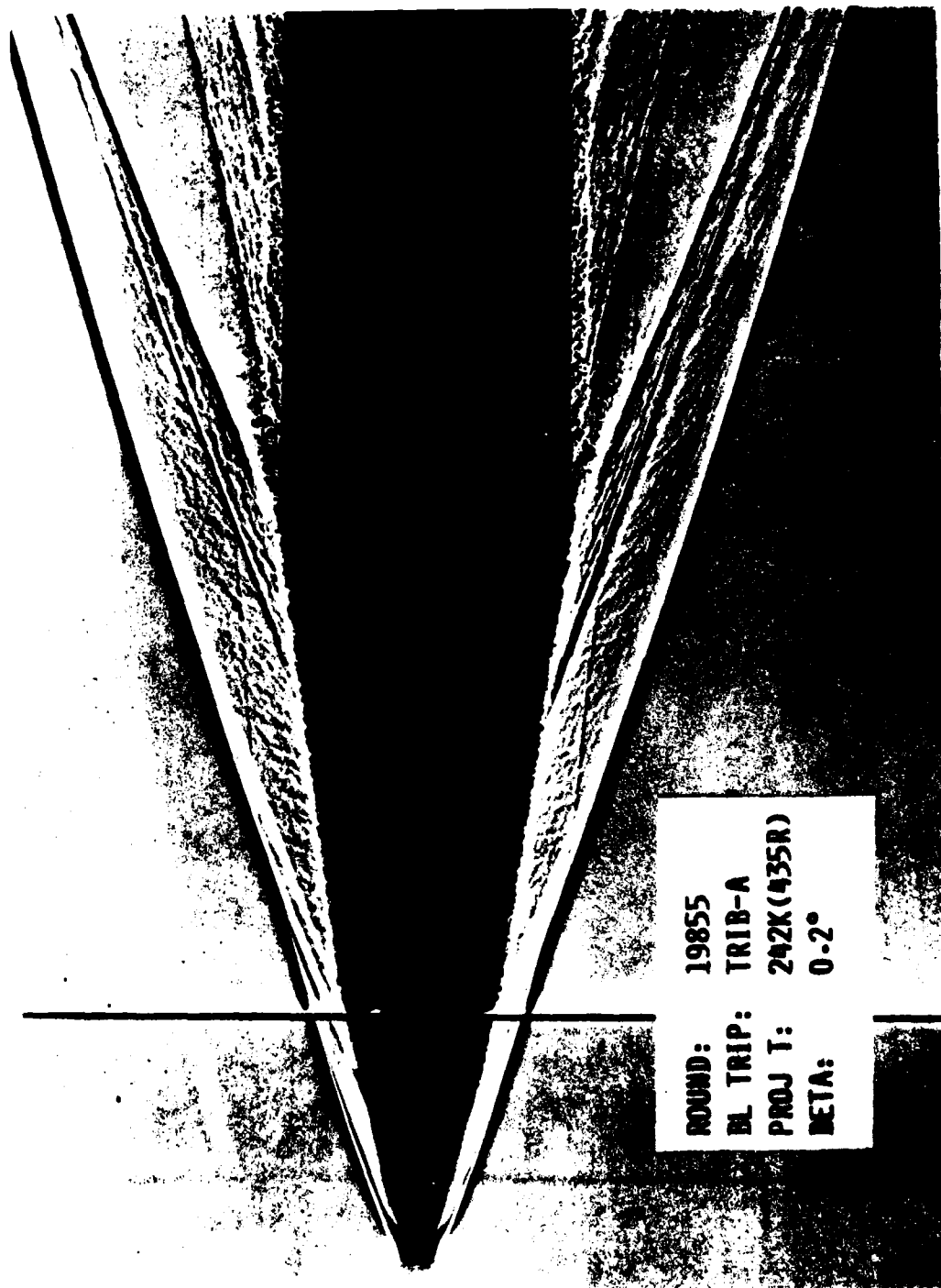


Figure 3. Spark Shadowgraphs, BL Trip-A

a. Round 19855, Wall Temp = 242K(435R),  $\beta = 0.2^\circ$

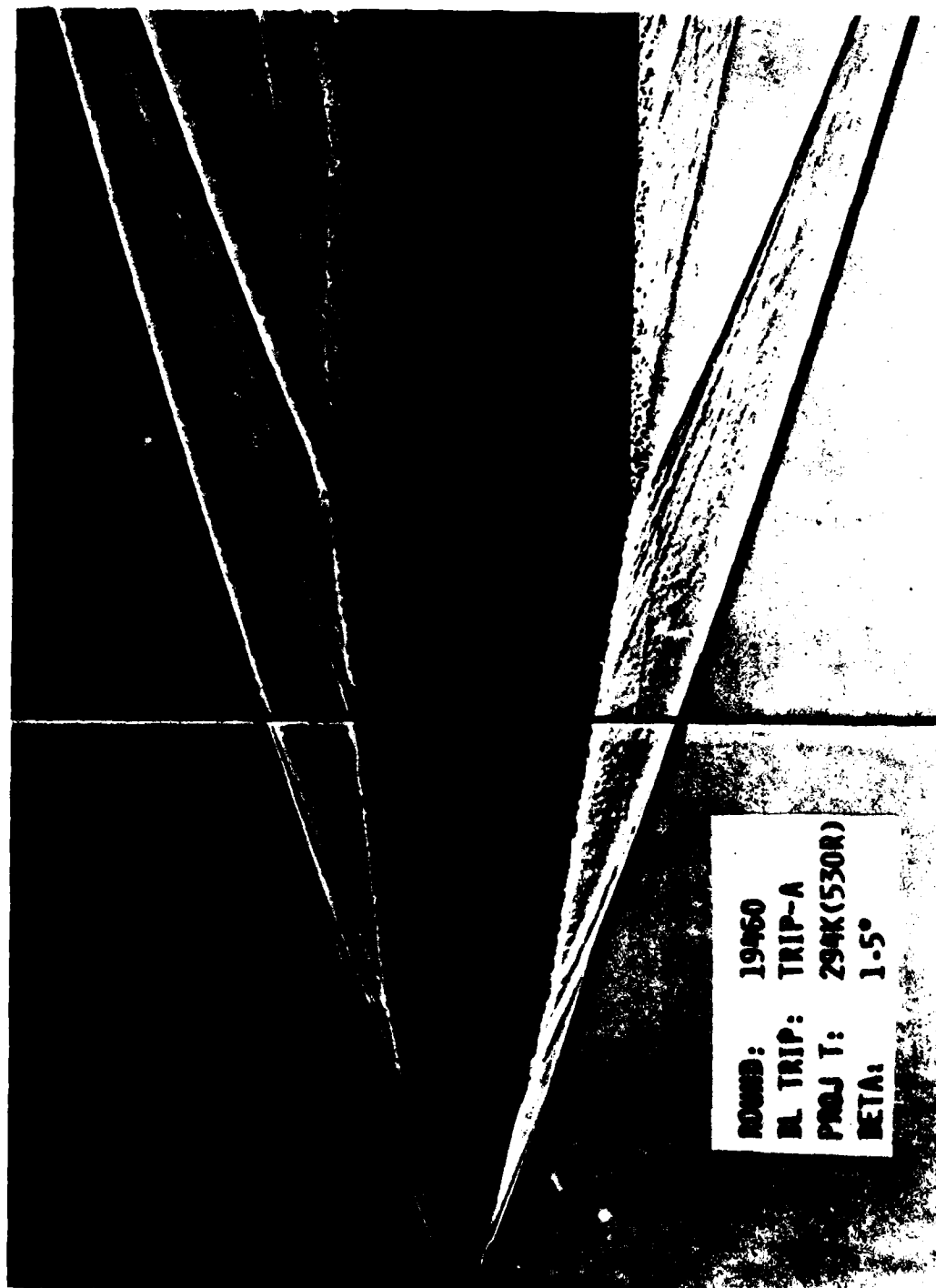


Figure 3. Spark Shadowgraphs, BL Trip-A

b. Round 19460, Wall Temp = 294K(530R),  $\beta = 1.5^\circ$

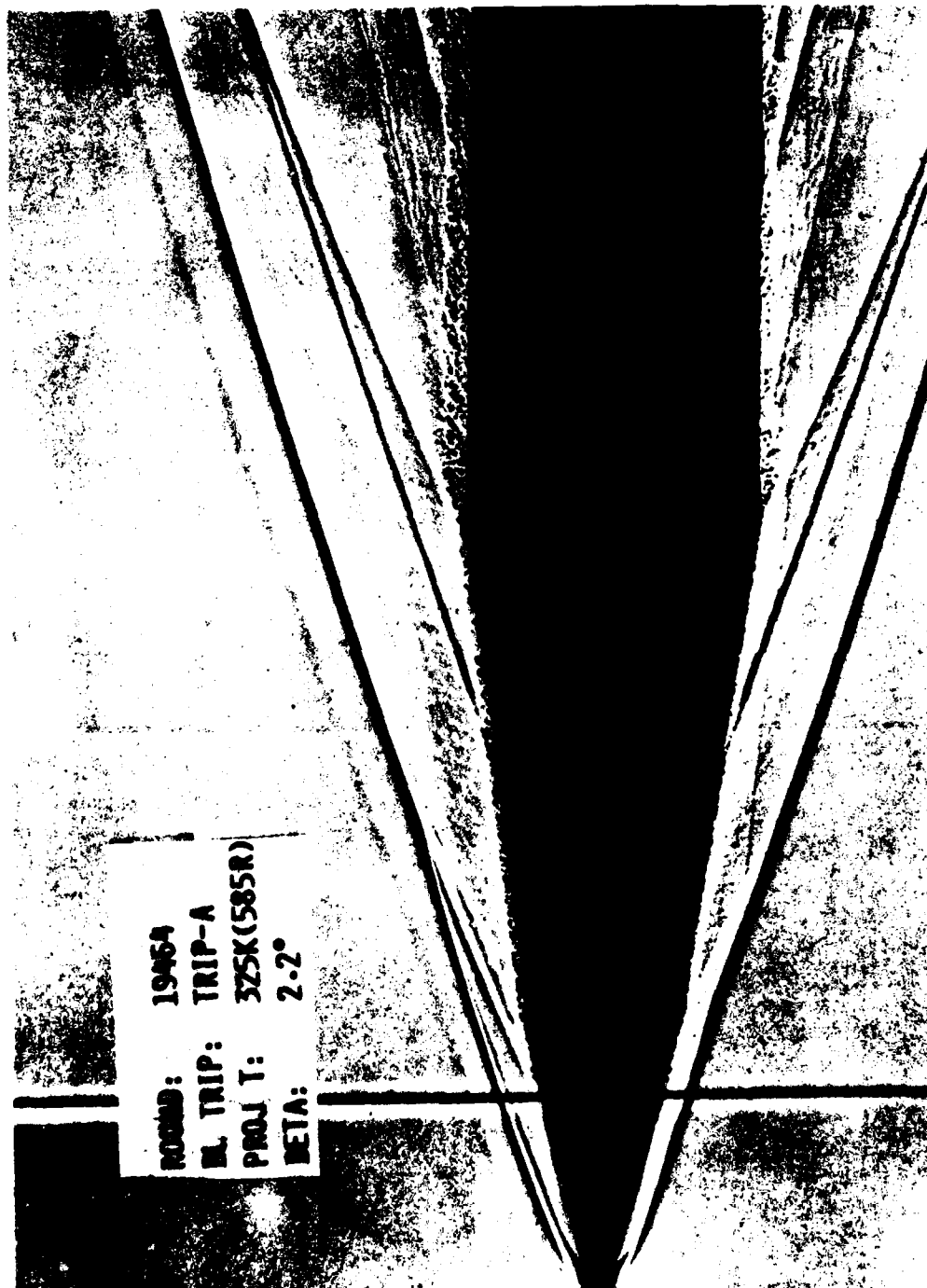


Figure 3. Spark Shadowgraphs, BL Trip-A  
c. Round 19464, Wall Temp = 325K(585R),  $\beta = 2.2^\circ$



Figure 4. Spark Shadowgraphs, BL Trip-B

a. Round 19856, Wall Temp = 242K(435R),  $\beta = 0.2^\circ$

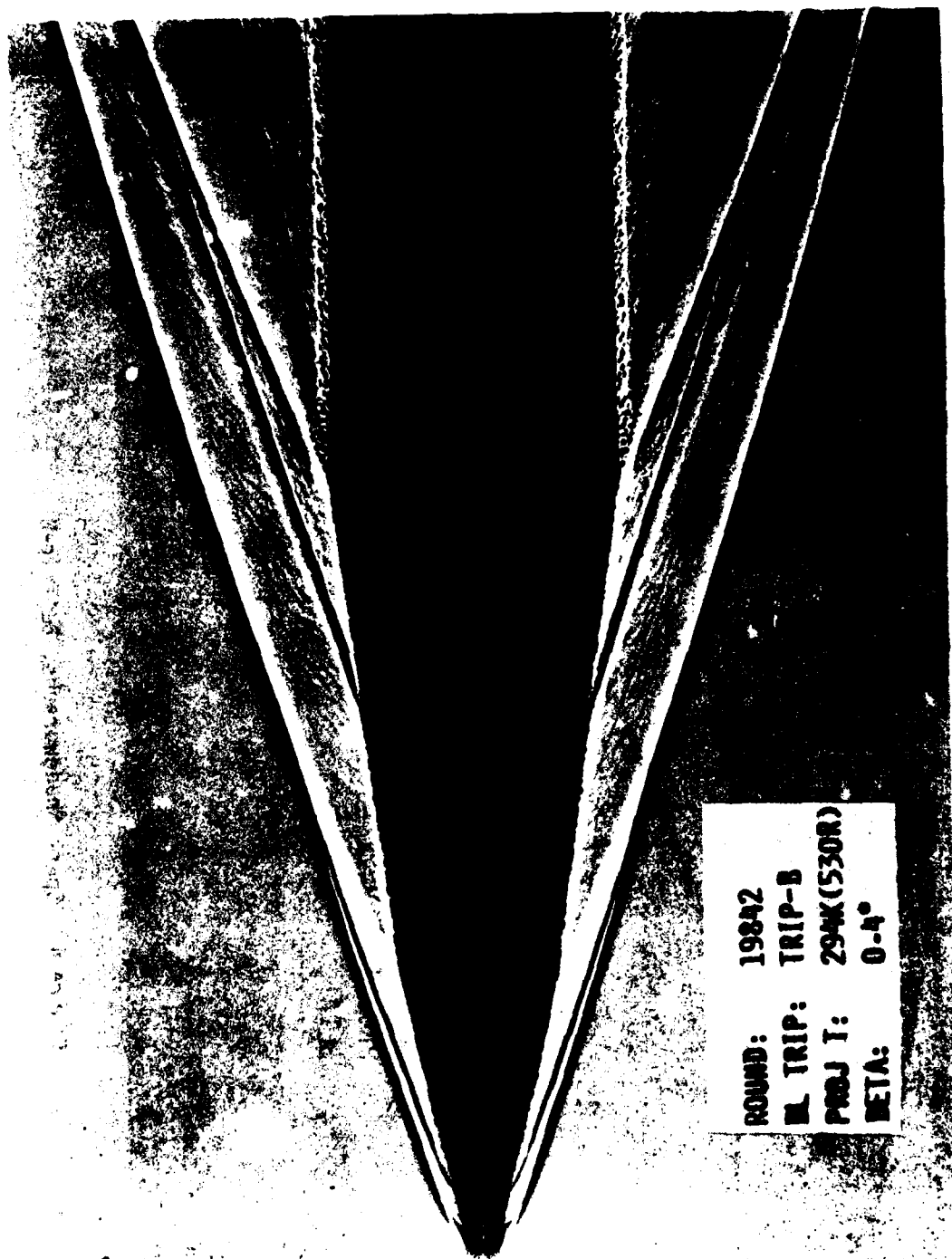


Figure 4. Spark Shadowgraphs, BL Trip-B  
b. Round 19842, Wall Temp = 294K(530R),  $\beta = 0.4^\circ$

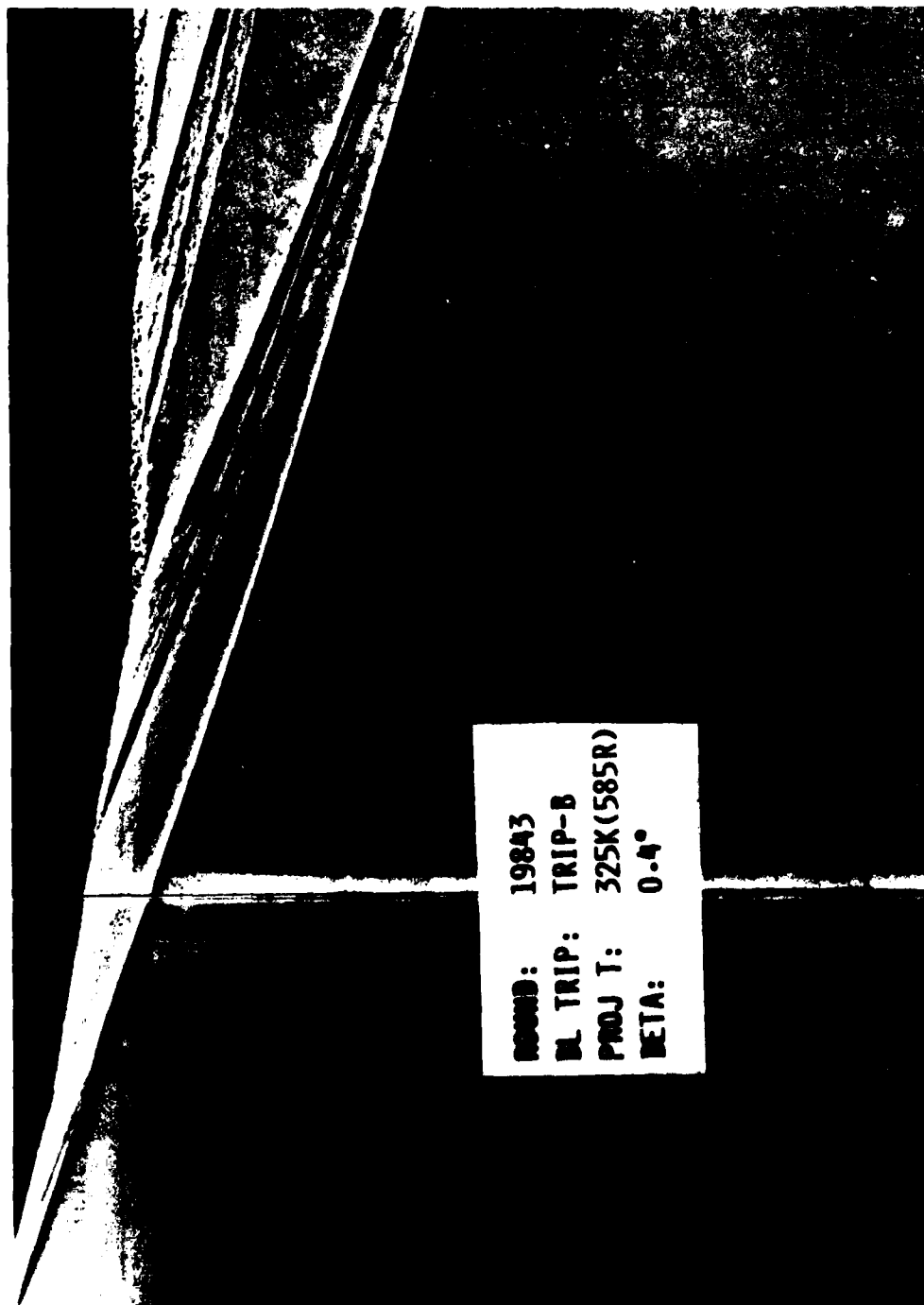


Figure 4. Spark Shadowgraphs, BL Trip-B  
c. Round 19843, Wall Temp = 325K(585R),  $\beta = 0.4^\circ$

# XM797 NOSE TIP

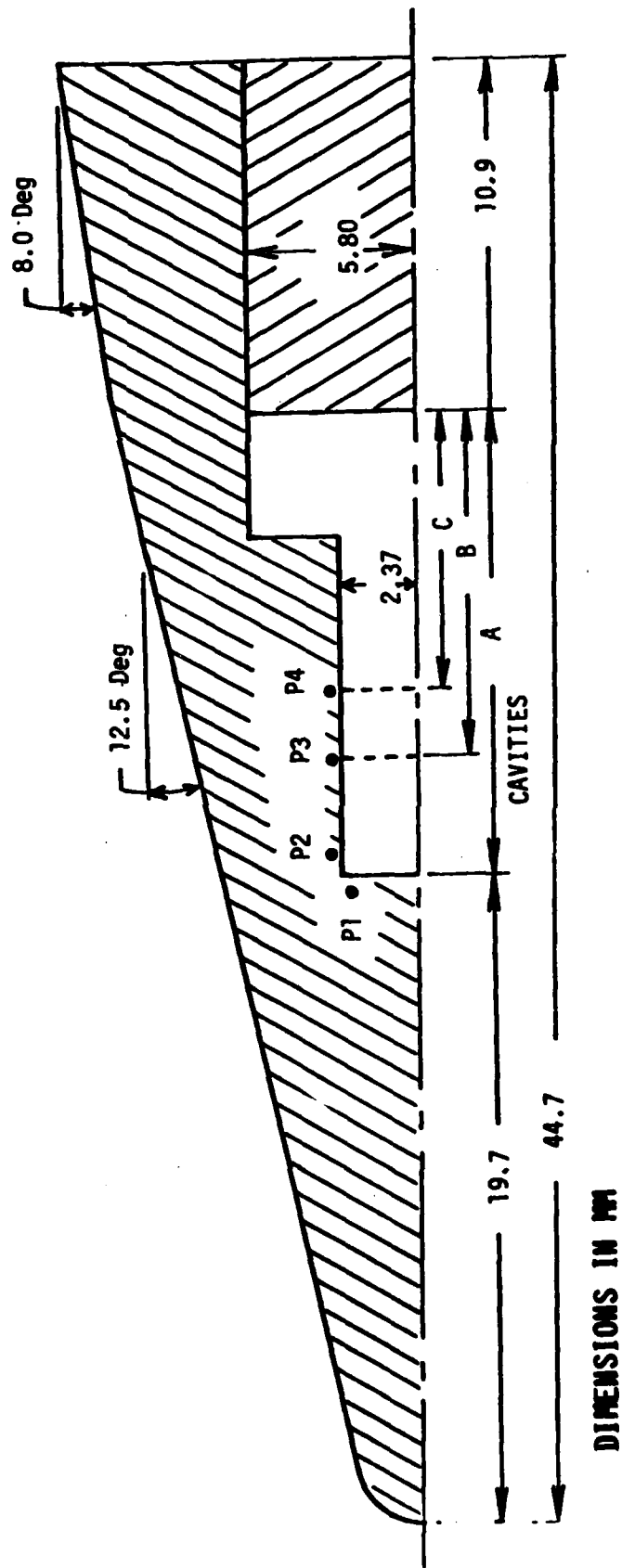


Figure 5. XM797 Nose-Tip Geometry, Computational Configuration

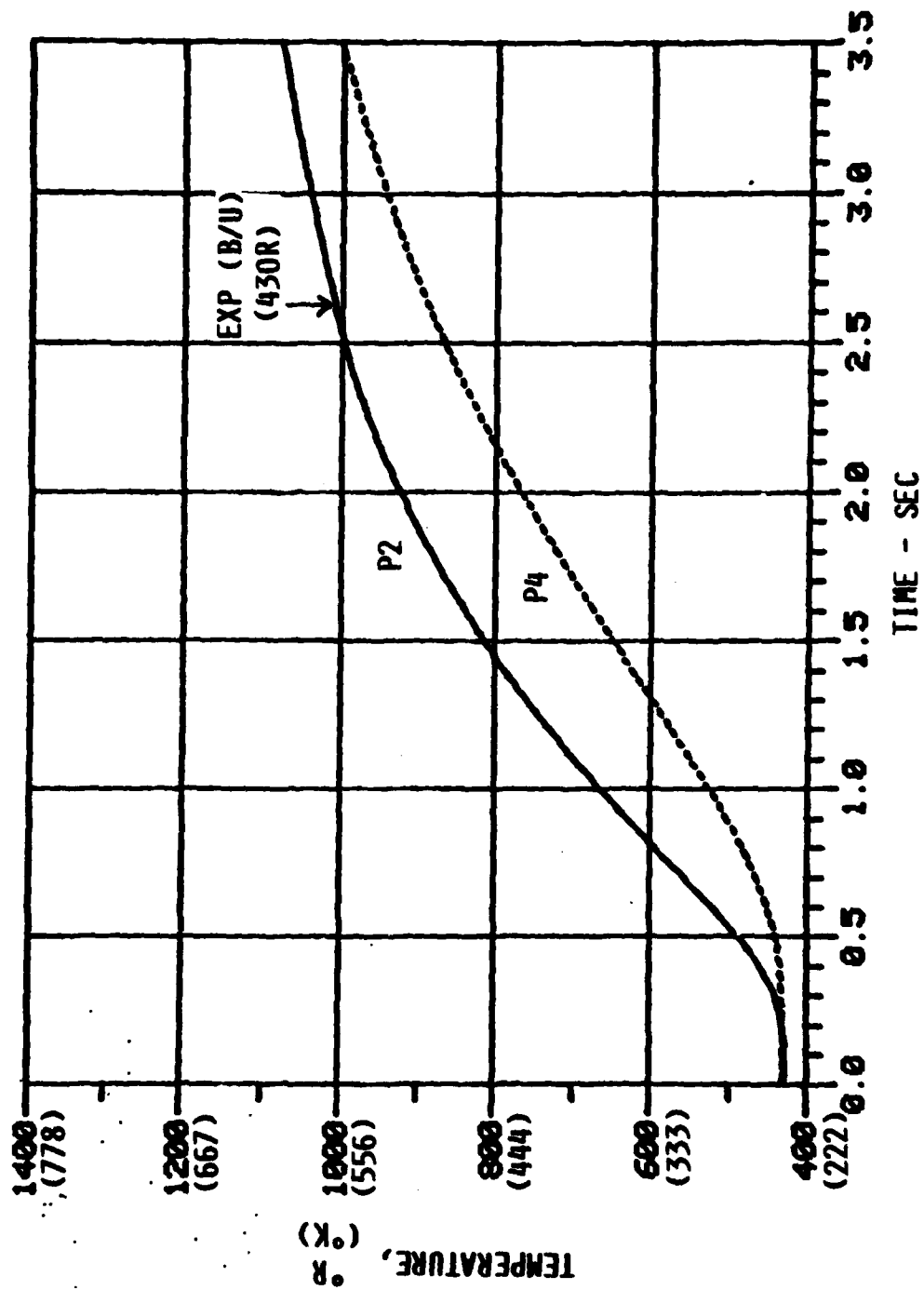


Figure 6. Critical Nose Temperature-Time History for a Stainless Steel Nose Tip with Long (P1) and Short (P2) Cavities

a. Cold Projectile, Wall Temp = 242K(435R)

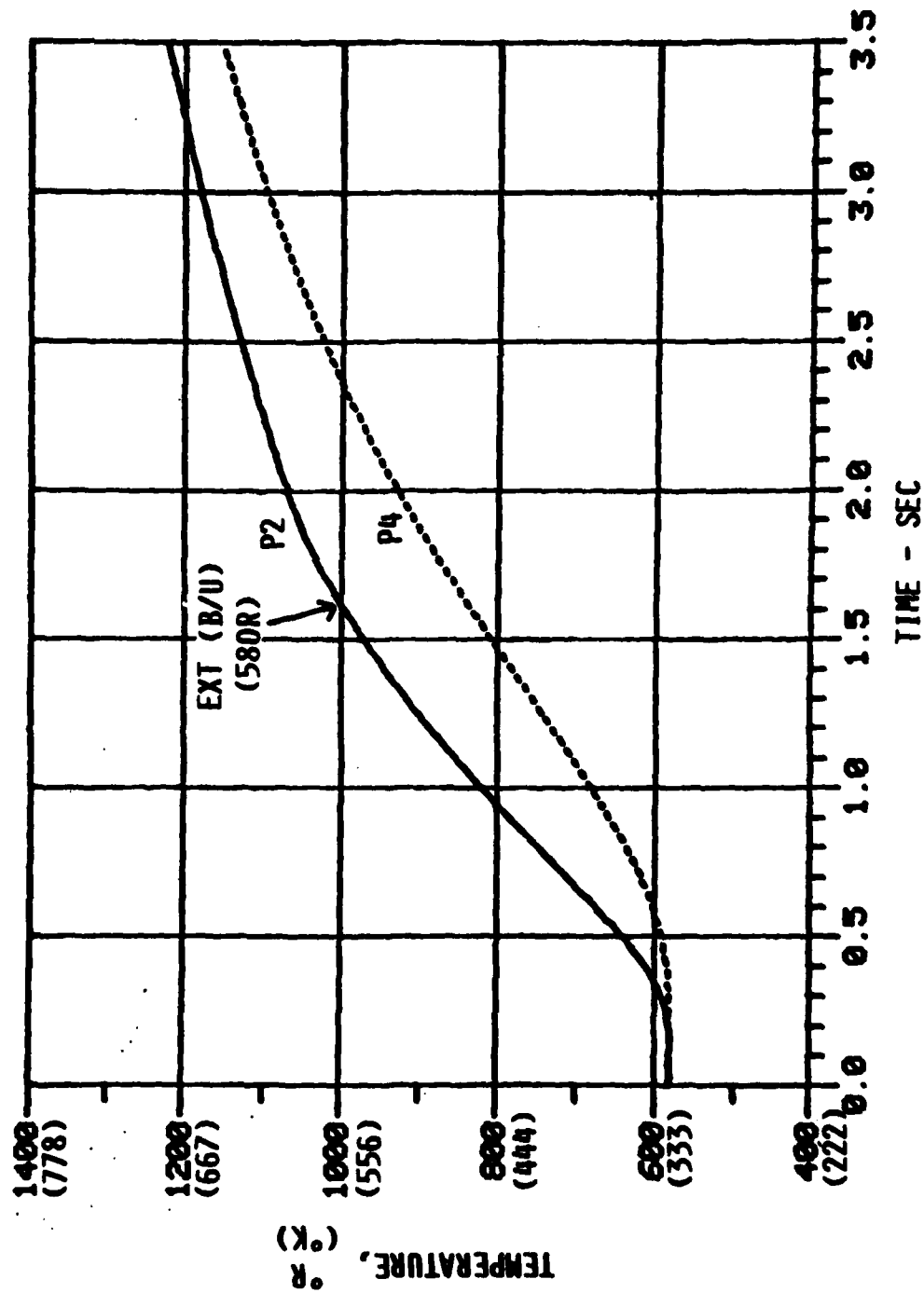


Figure 6. Critical Nose Temperature-Time History for a Stainless Steel Nose Tip with Long (P1) and Short (P2) Cavities

b. Hot Projectile, Wall Temp = 325K (535R)

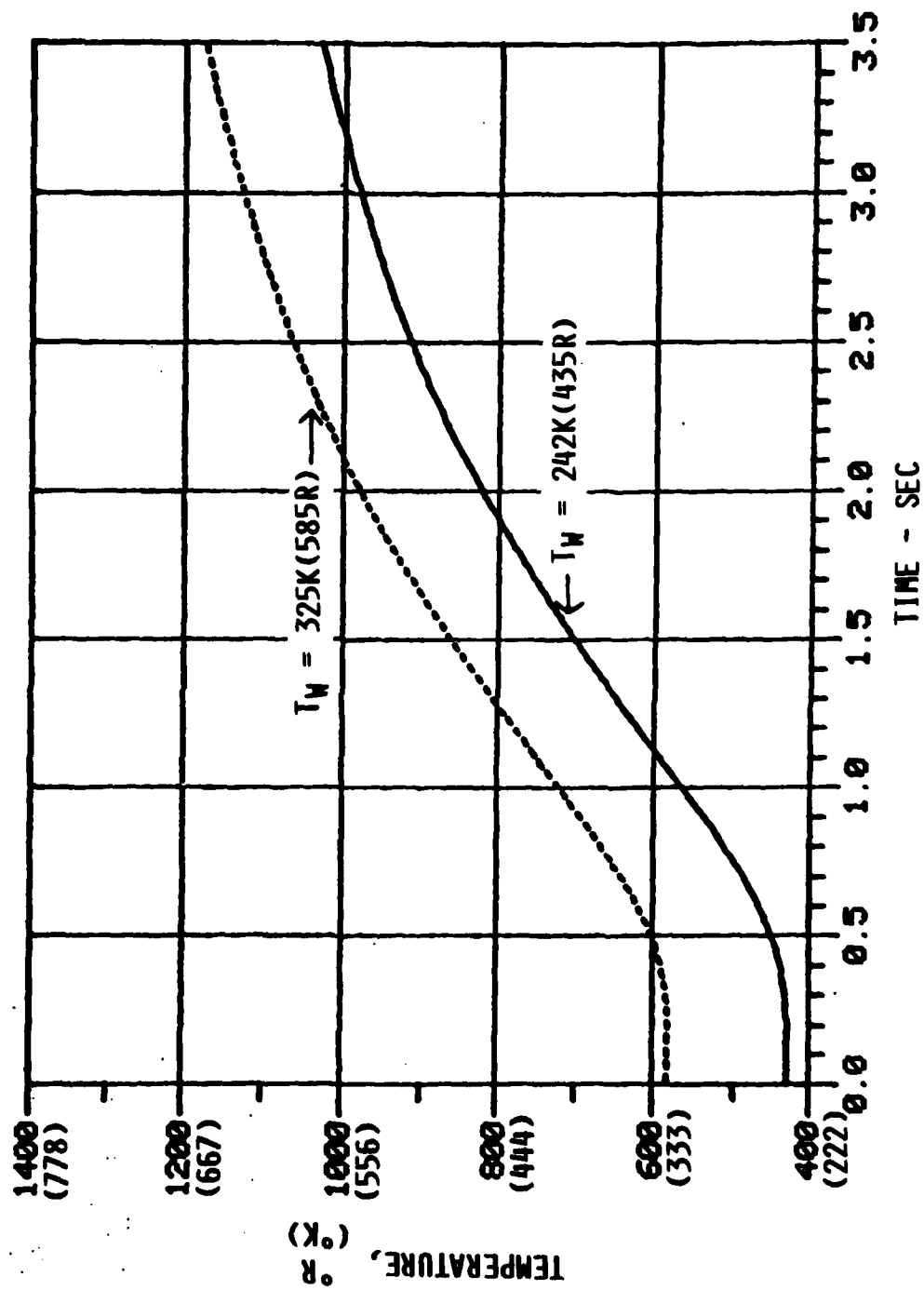


Figure 7. Critical Node Temperature-Time History for a Stainless Steel Nose Tip with Intermediate Length Cavity

TABLE 1. SUMMARY OF AERODYNAMIC DATA

BL TRIP	T <sub>w</sub> °K(°R)	ROUND	*U <sub>M</sub> M/S	*M	C <sub>D</sub>	C <sub>Mα</sub>	YAW <sub>AV</sub> - Deg
None	242(435)	19854	1507	4.40	.302(.5)**	-23.0(.8)	0.83
None	294(530)	19459	1478	4.24	.335(.6)	-24.4(.4)	2.04
None	294(530)	19461	1496	4.29	.324(.5)	-23.4(.9)	2.20
None	325(585)	19463	1499	4.32	.324(.9)	-23.4(.9)	1.35
None	325(585)	19465	1509	4.33	.324(.8)	-23.1(.8)	2.14
A	242(435)	19855	1516	4.42	.324(.7)	-22.2(.7)	1.72
A	242(435)	19857	1527	4.44	.319(.7)	-22.4(.6)	1.62
A	294(530)	19460	1502	4.31	.322(.6)	-23.2(.7)	1.41
A	325(585)	19464	1515	4.36	.321(.6)	-23.0(.7)	1.64
B	242(435)	19856	1523	4.43	.314(.7)	-22.4(.6)	1.65
B	294(530)	19842	1493	4.37	.306(.9)	-23.3(1.0)	0.97
B	325(585)	19843	1530	4.47	.302(.7)	-22.2(.9)	1.03

\*Velocity and Mach Number at the muzzle.

\*\*Values in parentheses under coefficient data are estimated RMS deviations (percent) between the measurements and a hypothetical set of true measurements free from observation errors.

TABLE 2. INPUT PARAMETERS

K1 = 1, Intrinsic roughness height, mil  
K2 = 1, Maximum turbulent roughness height, mil  
\*K3 = 4, Roughness near melt, mil  
\*K4 = 2, Laminar heating augmentation factor  
 $X_{TR}$  = 15mm, Location of transition from nose

\*Hudgins, H., Modification to ASCC-79, private communication, LCNSL/ARRADCOM, Dover, NJ.

#### REFERENCES

1. Sandhu, S. S., and Murray, A. L., "Reentry Vehicle Technology (REV-TECH) Program. Volume III. Improved Capabilities of the ARBES Shape Change Code (ASCC 79)," Acurex Report TR-79-10/AS, Acurex Corporation/Aerotherm, 485 Clyde Avenue, Mountain View, California 94042, prepared for Space and Missile Systems Organization, Air Force Systems Command, Los Angeles, California 90009, July 1979.
2. Hudgins, H., Private Communication, Results of XM797 August 1981 Firing Data.

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US Army Ballistic Research Laboratory  
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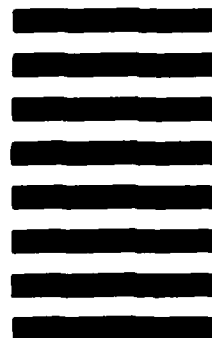


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